Progress Report No. 20

# A Theoretical and Experimental Study of the Ionosphere Using Radio Signals from Earth Satellites

Grant Number NGR 14-005-002

from

The National Aeronautics of Space Administration

K. C. Yeh, Principal Investigator

Period Covered: July 1, 1969 to December 31, 1969

January 9, 1970

The Electrical Engineering Research Laboratory
University of Illinois, Urbana-Champaign
with the Cooperation of the
University of Illinois Observatory
Urbana, Illinois

FACILITY FORM 602

N70-71512
(ACCESSION NUMBER)

(THRU)

17
(PAGES)

NONE
(CODE)

CR#107722
(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

# A THEORETICAL AND EXPERIMENTAL STUDY OF THE IONOSPHERE USING RADIO SIGNALS FROM EARTH SATELLITES

## Introduction

We report the progress of our ionospheric research during the period July 1 through December 31, 1969. The experimental program makes use of radio signals from artificial satellites. The principal signals used are VHF telemetry signals in the range 136-137 MHz from ATSIII and sometimes ATSI and Early Bird. These signals when interpretated yield information on the integrated electron density and on the existence of irregularities. The theoretical investigations are propagation of acoustic gravity waves, simulation and ray tracing analysis, ducting of electromagnetic waves in the magnetosphere, scattering from irregularities and propagation in a random medium.

The report is arranged under the following headings.

(1) Field Station Operation
(2) Equipment Development
(3) Data Reduction
(4) Traveling Disturbances
(5) Simulation and Analysis of Faraday Rotation of Beacon Satellite Signals in the Presence of Traveling Ionospheric Disturbances
(6) Scattering from Irregularities in an Anisotropic Plasma
(7) Trapping of Electromagnetic Waves by Nonlinear Resonant Interactions with Ion Sound Waves
(8) Long Wavelength Ion-Acoustic Waves in a Magnetoplasma in a Gravitational Field

(9) Papers Presented at Conferences

(10) Publications

(11) Personnel

1. Field Station Operation (B. J. Flaherty)

Faraday rotation measurements are being made at three stations using the transmissions from the ATS-III Satellite. These stations are separated by approximately 35 KM and are located at Oakland, Danville, and Urbana, Illinois.

The Ionosphere Radio Laboratory has acquired and taken over the operation of the Moon Reflection Laboratory field site in Danville, Illinois. Some of the major properties acquired include a 28-foot steerable parabolic reflector antenna with antenna feeds, mixers, amplifiers, and oscillators that cover the frequency range from VHF to about GHz. This station is a valuable addition to our experimental capability.

The polarimeter used in Danville consisted of a rotating feed (48 rpm) and a null detector to measure the Faraday rotation. The previous operator told us that they had periodic maintenance problems with the rotating feed and coaxial joint. Since we planned to operate the station unattended for periods up to two weeks, it was felt that the old polarimeter would be too unreliable. A polarimeter of our design was installed. To install the polarimeter a three element crossed yagi feed antenna had to be built and balanced low loss coaxial cables installed. This polarimeter has been in operation since 3 December 1969. Preventative maintenance was performed on the antenna's electrical and mechanical drive systems to ensure the dish and work on the pointing accuracy of the dish. (At present there is about a 2°-3° pointing error).

A WWV monitoring station has been in operation at the Danville site since October 1969. We are recording receiver agc levels (10, 15, 20, 25 MHz) on an Offner ink recorder. After sufficient data has been collected,

we intend to look for correlations between WWV reception and total electron content. That is, we hope to be able to predict which WWV path will be open based on T.E.C. measurements. Mr. Joseph Lombardo is currently working on this problem.

2. Equipment Development (B. J. Flaherty)

A solid state ATS-III receiver has been developed that works in connection with the Model "B" receiver. This receiver is to be the basis of a solid state electronic polarimeter. We intend to have this operational in spring or early summer.

Some preliminary work has been done in the design of a digital data system. More work will be done on this in the following months.

3. Data Reduction (B. J. Flaherty)

All of the ATS-III total electron content data from January 1, 1968 to 1 August 1969 have been reduced to absolute rotation data. (This data is one IBM punch cards). We are now in the process of calibrating the absolute rotation to TEC curves. At present, 1 January 1969 to 31 March 69 are reduced to TEC values. Enclosed with this report are representative quiet and magnetically active diurnal curves, a weekly and a monthly average curve. The weekly and monthly plots also have the standard of deviation plotted on them as error bars. We plan to have all of the back data reduced to TEC values by June 1970.

One year's worth of records (1 January 1969 - 31 December 1969) has been scaled to study the occurrence of periodic fluctuations in the absolute rotation values. The items scaled from the records are (1) the approximate period, (2) the amplitude [in $\pi$ rad.), (3) the duration (in local time) of the fluctuations. We plan to analyze these data to see if there is a seasonal or diurnal dependence.

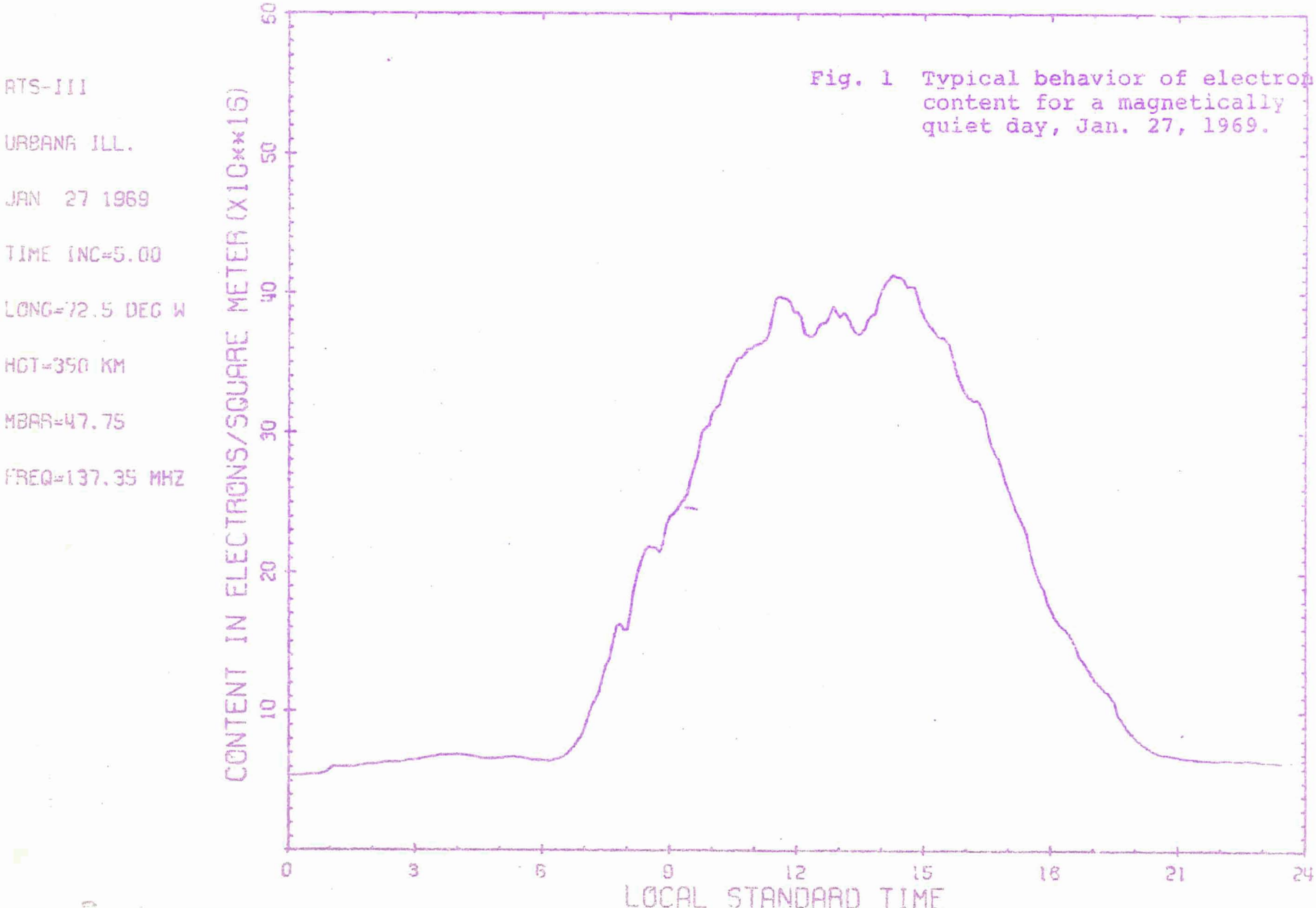


Fig. 1 Typical behavior of electron content for a magnetically quiet day, Jan. 27, 1969.

ATS-III

URBANA ILL.

FEB 2 1969

TIME INC=5.00

LONG=72.7 DEG W

HGT=350 KM

MBAR=47.75

FREQ=137.35 MHZ

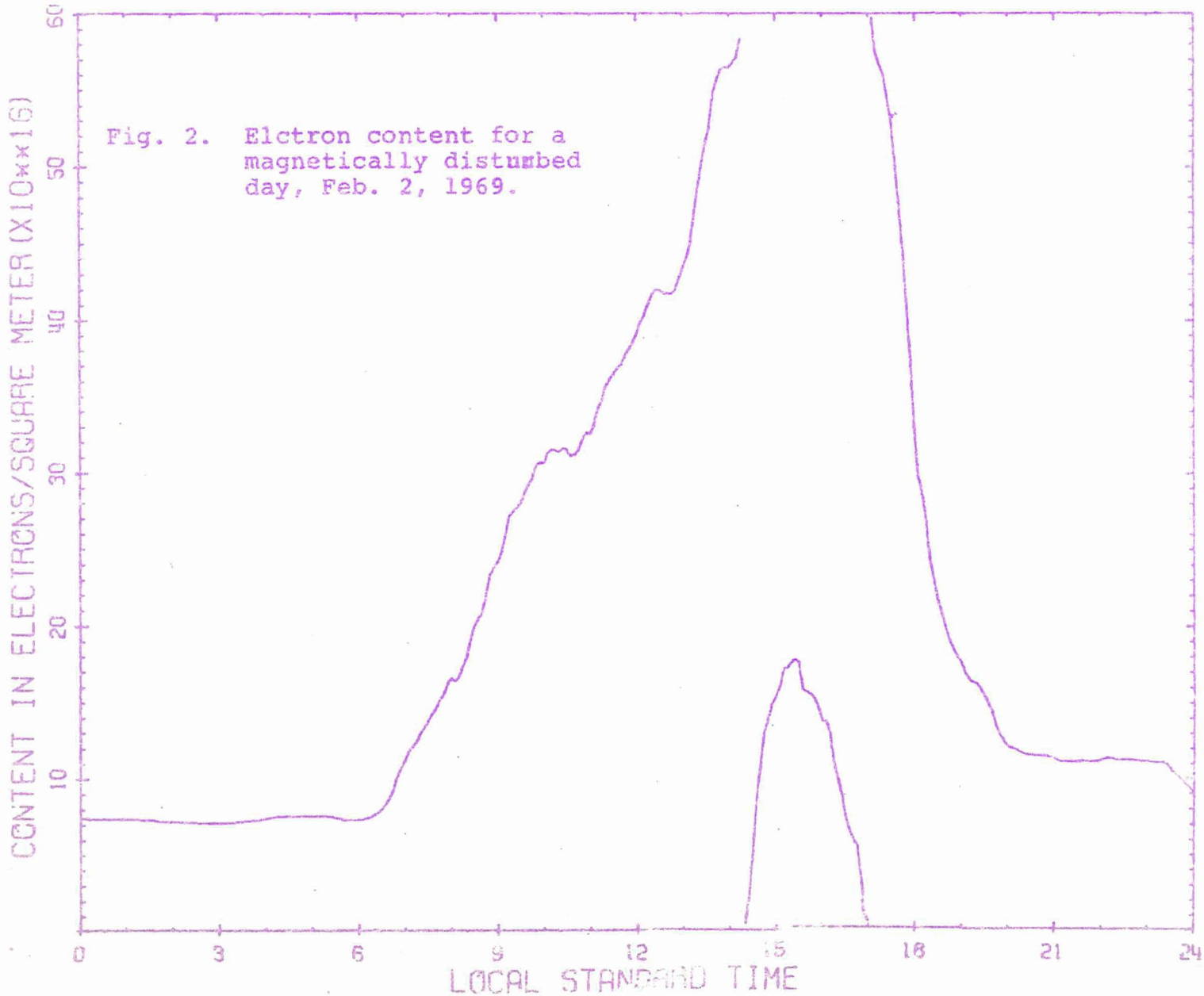


Fig. 2. Elctron content for a magnetically distumbed day, Feb. 2, 1969.

ATS-III

URBANA ILL.

FROM 690101

TO 690107

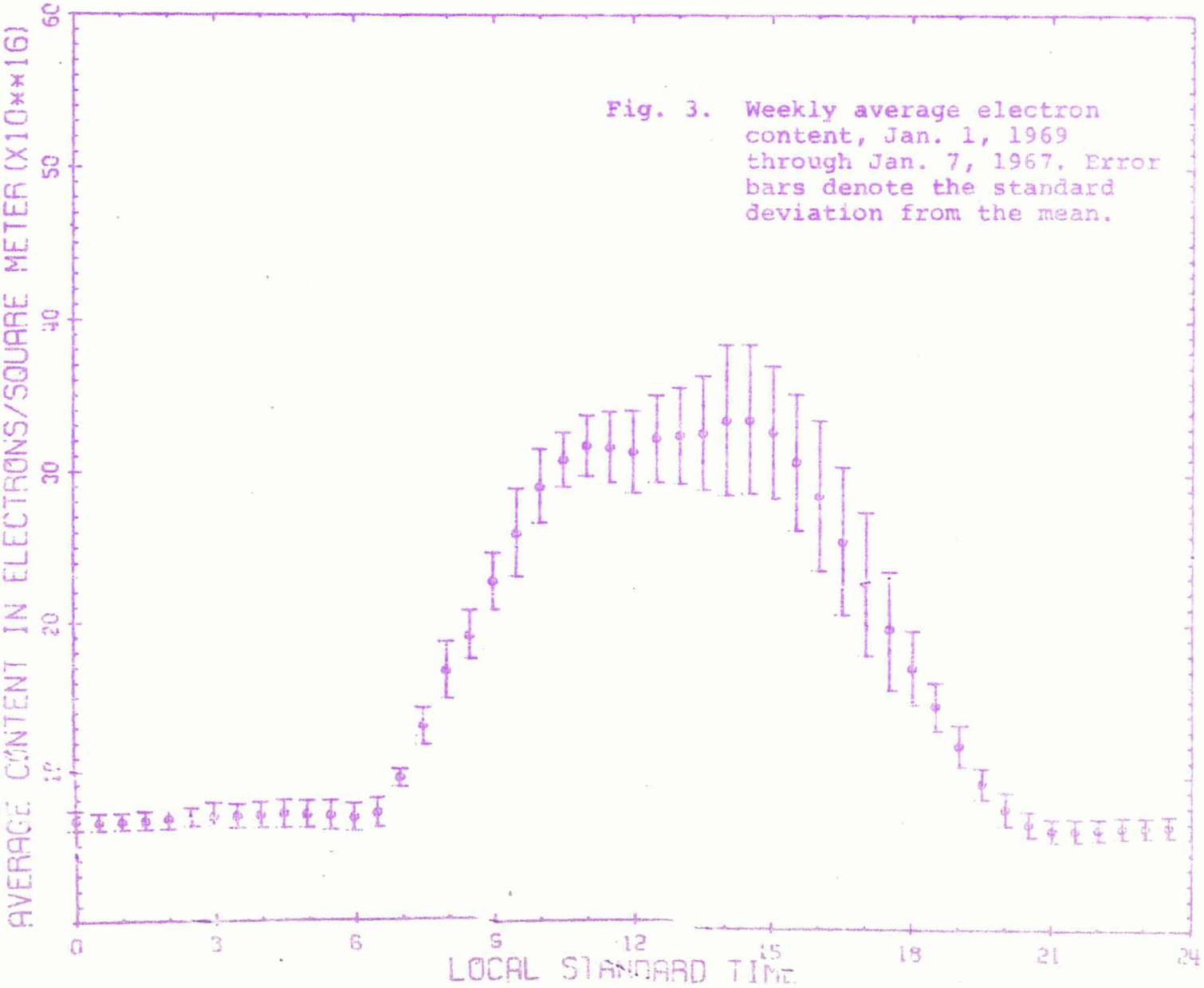


Fig. 3. Weekly average electron content, Jan. 1, 1969 through Jan. 7, 1967. Error bars denote the standard deviation from the mean.

ATS-III

URBANA ILL.

FEB 2 1969

TIME INC=5.00

LONG=72.7 DEG W

HGT=350 KM

MBAR=47.75

FREQ=137.35 MHZ

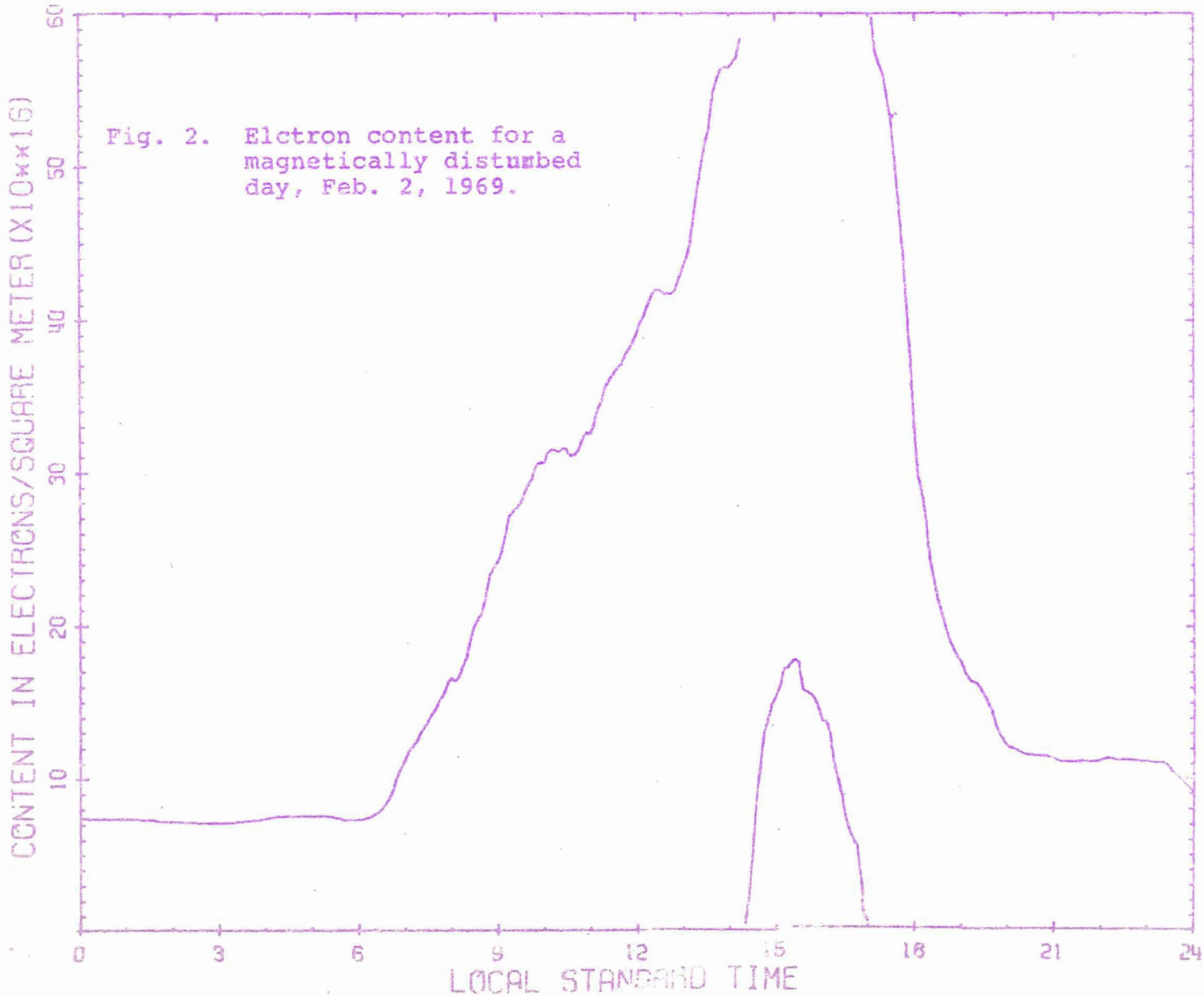


Fig. 2. Elctron content for a magnetically distumbed day, Feb. 2, 1969.

ATS-III

URBANA ILL.

FROM 690101

TO 690107

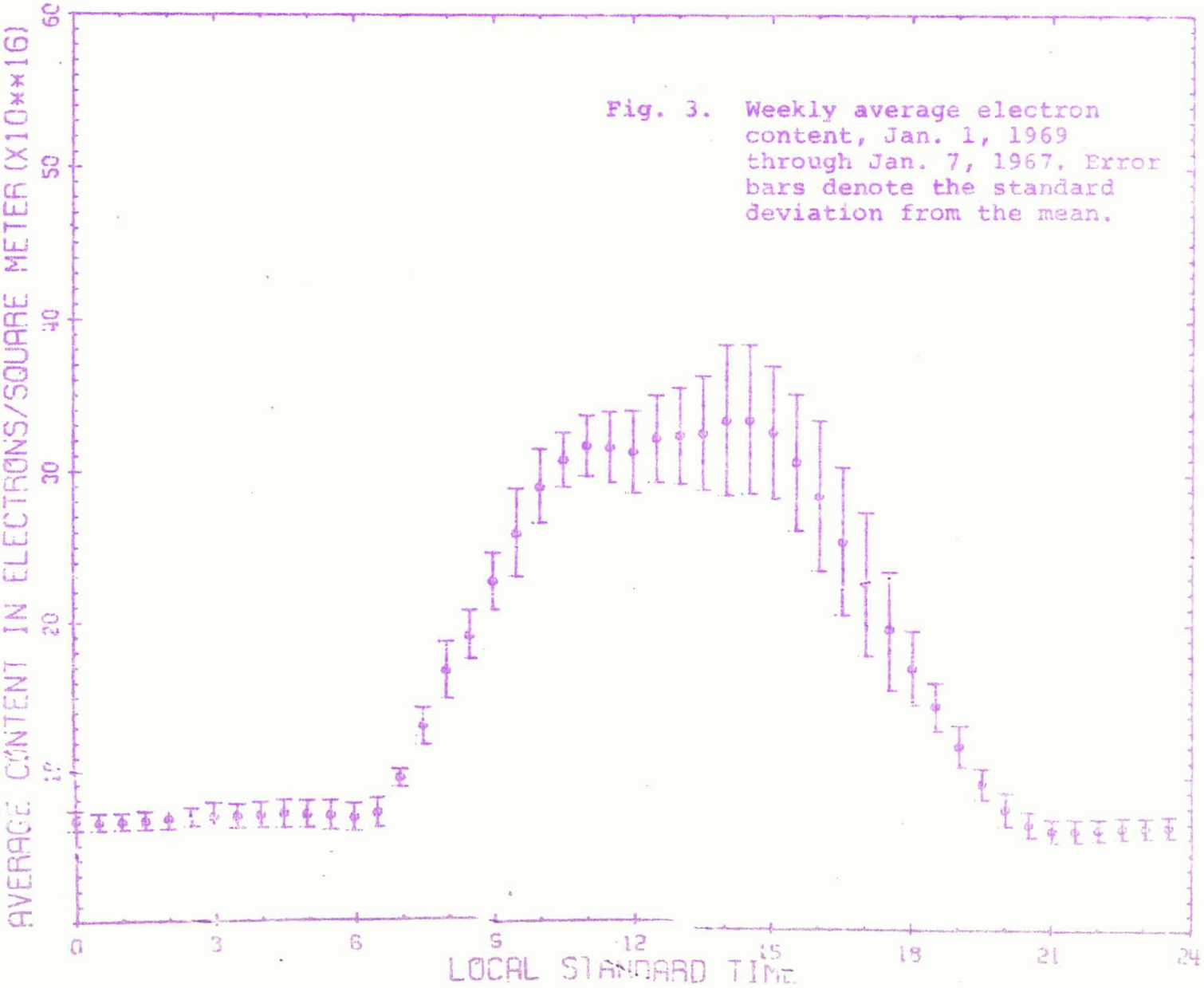


Fig. 3. Weekly average electron content, Jan. 1, 1969 through Jan. 7, 1967. Error bars denote the standard deviation from the mean.

ATS-III

URBANA ILL.

FROM 690101

TO 690131

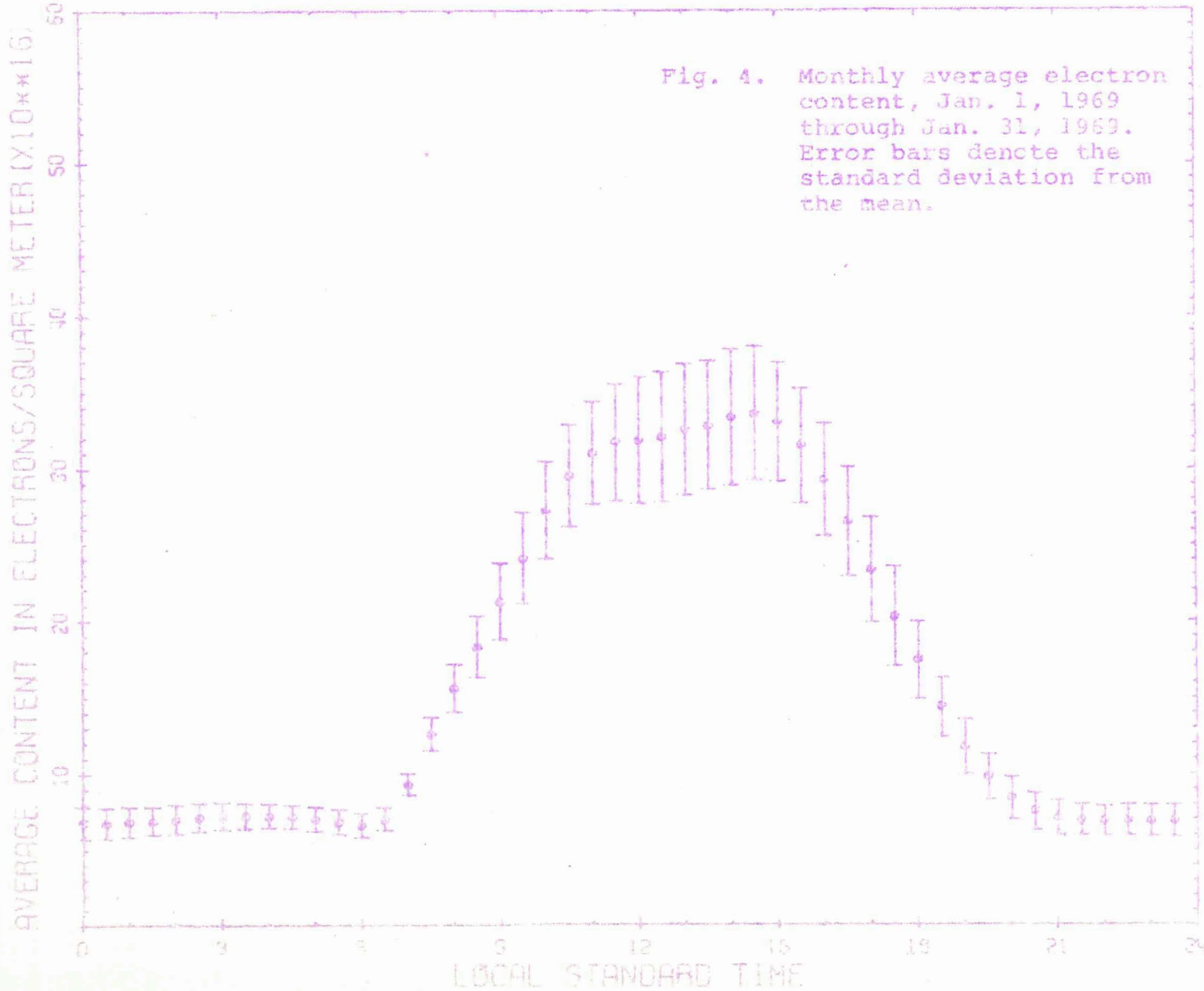


Fig. 4. Monthly average electron content, Jan. 1, 1969 through Jan. 31, 1969. Error bars dencte the standard deviation from the mean.

ATS-III

URBANA ILL.

FROM 690101

TO 690131

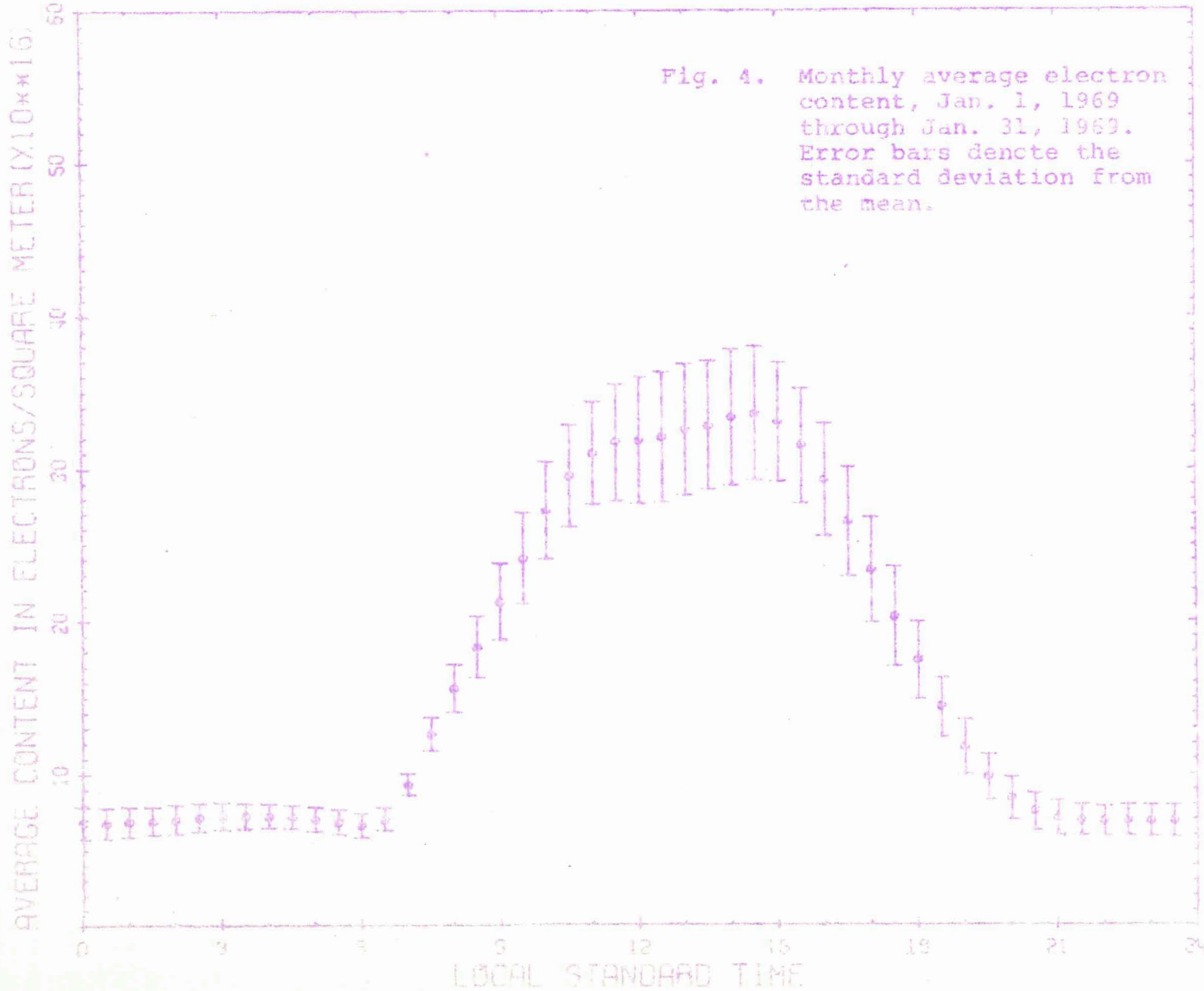


Fig. 4. Monthly average electron content, Jan. 1, 1969 through Jan. 31, 1969. Error bars dencte the standard deviation from the mean.

4. Traveling Disturbances (K. C. Yeh)

Recordings made at three stations mentioned in 1. have been used to study traveling disturbances. These disturbances are defined as those events that perturb the ionospheric electron density in a sinusoidal fashion. The perturbation in the density is caused by the passage of acoustic gravity waves. Statistics on wave properties such as direction, period, wavelength, etc. have been obtained. These results are being written up as a Ph.D. thesis by D. H. Cowling. Also studied in the thesis are the effects of horizontal winds on the propagation of acoustic gravity waves. The effects are found to be very marked as the wind speed in the upper atmosphere may be as high as 100-200 m/sec. which is an appreciable fraction of the speed of sound. The presence of these strong winds has the effect of selecting only those waves propagating in a preferred direction. Details can be found in the thesis which will also be printed as a technical report.

5. Simulation and Analysis of Faraday Rotation of Beacon Satellite Signals in the Presence of Traveling Ionospheric Disturbances (N. Narayana Rao)

This work is a continuation of the topic entitled "Computer simulation of Faraday rotation of artificial earth satellite signals during traveling ionospheric disturbances" described in Progress Report No. 19. Using the method of simulation described in that progress report, Faraday rotation data have been simulated to study the following effects: a) cancellation of changes in polarization rotation due to increases and decreases in ionization along the ray path from the satellite to the receiver,

and b) assumption of a height value for computing the ionospheric locations corresponding to the stations in the orbiting satellite case. The following conclusions have been reached:

a) Cancellation effect: The results of simulation bear out quantitatively the intuitive expectations based on the characteristics of the disturbing wave in relation to the geometry of the ray path from the satellite to the receiver. While the cancellation effect acts on the transmissions from the geostationary satellites and the orbiting satellites in the same manner, short wavelength fluctuations which may not be observable by using geostationary satellites because of the fixed geometry may be observable by using orbiting satellites because of their changing attitude with respect to the direction of travel of the wave during the course of their orbits. On the other hand, long wavelength fluctuations observable by geostationary satellites may not be observable by the orbiting satellite technique simply because of the finite length of the passage.

b) Height assumption for the orbiting satellite case: Two examples, one for stations with small spacing (Urbana, Danville and Brocton, Illinois) and the second for stations with large spacing (Urbana, Illinois; London, Ontario; Hamilton, Massachusetts), have been considered to evaluate the height assumption. It has been found that the parameters of the disturbance deduced from the simulated data vary widely with the assumed height for the small spacing case whereas they are relatively uninfluenced by the height assumption for the large spacing case. It is suggested that large spacings be used for future spaced receiver experiments involving orbiting beacon satellites such as the Canadian ISIS series.

6. Scattering from Irregularities in an Anisotropic Plasma (D. Simonich)

The bi-static scattering problem, in which a radio wave is beamed at a region in a magneto-plasma in which there are random deviations of electron density and the scattered energy is received at another location, has been solved under certain assumptions. The present solution is valid for a narrow beam or a small scattering volume and the scattering is first order. Solutions have been found for both the received power and the scattering cross-section. There is some coupling of modes but due to the complicated nature of the equations, the amount of coupling can only be determined from numerical examples which I am about to start programming on the computer. The volume restriction may be relaxed somewhat when the work on the slab problem is complete.

The problem of receiving radio waves after they have passed through a slab of irregularities requires a more refined solution. At the present time, I am assuming a Taylor's series expansion in the plane of the slab for the propagation vector. This should give a more accurate expression for the phase of the wave which is necessary for the larger scattering volume encountered in this problem.

7. Trapping of Electromagnetic Waves By Nonlinear Resonant Interactions With Ion Sound Waves (C. H. Liu)

The nonlinear perturbation technique used in studying resonant wave-wave interaction is applied to a three-wave system in an isotropic plasma. The three waves are: one ion sound wave and two electromagnetic waves. The emphasis is on the possibility of trapping of the electromagnetic waves. It is found that for the special case in which the frequency of ion sound wave is much less than the frequency of the electromagnetic waves, the

interaction is such that energy exchange takes place only between the two high frequency waves. The ion sound wave does not participate in the energy exchange process but acts as a kind of catalyst for the interaction. The analysis indicates that he electromagnetic energy is trapped within a certain spatial region perpendicular to the propagation direction of the ion sound wave. The trapping width is found to depend, among other parameters, on the magnitude of the ion sound wave perturbation.

The analysis is now being extended to the case of magneto sma. In principle, the interaction mechanism is the same as that for the isotropic case but the trapping width is modified.

This resonant interaction scheme is proposed as one possible mechanism for field-aligned propagation of electromagnetic waves in the ionosphere as observed by the topside sounding experiments. Since it is well known that ion sound waves in a magnetoplasma are strongly Landau damped when propagating along the magnetic field but not when propagating across it, it is conceivable that the damping mechanism selects only those ion sound waves that propagate perpendicular to the magnetic field lines in the ionosphere. These ion sound waves can confine the electromagnetic waves to propagate along the magnetic field lines through the resonant interaction we proposed.

The results have been written up as a paper and submitted for publication.

8. Long Wavelength Ion-Acoustic Waves in a Magnetoplasma in a Gravitational Field (C. H. Liu)

In an isothermal atmosphere supported by gravity, acoustic-gravity waves propagating in the direction of decreasing density will steepen until shock waves are formed. A similar situation will occur for ion-acoustic waves in a plasma supported by gravity according to the fluid picture.

But in a plasma where ion-ion collision is negligible and wave-particle interaction becomes important, it is no longer appropriate to use the fluid dynamic picture to discuss the problem. Instead, kinetic equation should be applied. This problem is studied for a magnetoplasma supported by a gravitational field via the three dimensional Vlasov equations. It is found that Landau damping process is competing with the exponential growth of the wave due to gravitational field. Under certain conditions Landau damping may indeed prevent the ion-acoustic waves from steepening into shock waves. This Landau damping of the ion-acoustic waves propagating in the direction of decreasing plasma density may be considered as a heat source in the plasma in a gravitational field. Possible applications of the theory to the problem of heating of the solar corona and heating in the magnetosphere are discussed.

The results have been written up as a paper and submitted for publication. They have also been presented at the 1969 Plasma Physics Meeting of the American Physical Society.

## 9. Papers Presented at Conferences

The following papers were presented:

(1) L. M. Paul, K. C. Yeh and B. J. Flaherty, "Measurement of Irregularity Heights by the Spaced Reciever Technique," Symposium on the Application of Atmospheric Studies to Satellite Transmissions, September 3-5, 1969, Boston.

(2) L. T. Hamrick and N. N. Rao, "Computer Simulation of Faraday Rotation of Beacon Satellite Signals during Traveling Ionospheric Disturbances," Symposium on the Application of Atmospheric Studies to Satellite Transmissions, September 3-5, 1969, Boston.

(3) C. H. Liu, "Long Wavelength Ion Acoustic Waves in a Magnetoplasma in a Gravitational Field," American Physical Society Plasma Physics Conference, November 9-12, 1969, Los Angeles.

## 10. Publications

(1) K. C. So and C. H. Liu, "A New Proof of Superposition of Dressed Particles in Plasma Kinetic Theory". J. Phys. A., 2, 605-610, 1969.

(2) C. H. Liu, "Propagation of Coherent Magnetohydrodynamic Waves".Physics of Fluids, 12, No. 8, 1642-1648, 1969.

(3) K. C. Yeh and C. H. Liu, "On Resonant Interaction of Acoustic-Gravity Waves". To appear in the Jan. 1970 issue of Radio Science.

(4) N. Narayana Rao, K. C. Yeh and M. Y. Youakim, "Ionospheric Electron Content at Temperate Latitudes during the Increasing Phase of the Solar Cycle". To appear in the Jan. 1970 issue of Australian Journal of Physics.

(5) M. Y. Youakim and C. H. Liu, "Propagation of Coherent Waves in a Warm Turbulent Magnetoplasma". To appear in the April, 1970 issue of Radio Science.

(6) C. H. Liu, "Ducting of Acoustic-Gravity Waves in the Atmosphere with Spatially Periodic Wind Shears". To appear in J. Geophys. Res.

(7) L. M. Paul, K. C. Yeh and B. J. Flaherty, "Measurement of Irregularity Heights by the Spaced Receiver Technique". To appear in Radio Science.

(8) K. C. Yeh and C. H. Liu, "Trapping of Electromagnetic Waves by Nonlinear Resonant Interaction with Ion Sound Waves". Submitted to Space and Planetary Science.

(9) C. H. Liu, "Long Wavelength Ion Acoustic Waves in a Magnetoplasma in a Gravitational Field". Submitted to J. Plasma Physics.

(10) C. H. Liu, "Propagation of Acoustic-Gravity Waves in a Turbulent Atmosphere". Submitted to Annales de Geophysique.

## 11. Personnel

The following persons have contributed to the work of the project during this report period:

Dr. K. C. Yeh, Professor of Electrical Engineering
Dr. N. Narayana Rao, Associate Professor of Electrical Engineering
Dr. C. H. Liu, Assistant Professor of Electrical Engineering
Mr. B. J. Flaherty, Research Engineer
Mr. Anthony Szelpal, Electronics Technician II
Mr. D. Simonich, Research Assistant (not paid by the project)
Mr. D. H. Cowling, Teaching Assistant (not paid by the project)
Mr. Joseph Lombardo, Research Assistant
Mrs. Nancy Wilson, Steno III

Several hourly student assistants have also been employed.